ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ
АКАДЕМИЯСЫ» РҚБ

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»

N E W S

OF THE NATIONAL ACADEMY
OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

1 (469)

JANUARY – FEBRUARY 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 1. Number 469 (2025), 59–71

https://doi.org/10.32014/2025.2518-170X.476

UDC 681.878

B.S. Ermakov[1], O.V. Shvetsov[1], S.B. Ermakov[1], S.A. Vologzhanina[2], 2025.
[1] Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia;
[2] Empress Catherine II Saint Petersburg Mining University,
Saint-Petersburg, Russia.
E-mail: svet_spb@mail.ru

INVESTIGATION OF THE INFLUENCE OF CAST MICROSTRUCTURE ON THE OPERABILITY OF THE CROWN OF A QUARRY EXCAVATOR

Ermakov Boris S. Dr. Sc., Professor, Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia, e-mail: ermakov_bs@spbstu.ru, ORCID ID: 0000-0003-4243-0984;
Shvetsov Oleg V. - Cand. Sc., Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia, e-mail: shvetsov_ov@spbstu.ru, ORCID ID: 0000-0001-9368-4074;
Ermakov Sergey B. - Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia, e-mail: ermakov_sb@spbstu.ru, ORCID ID: 0000-0003-4243-0984;
Vologzhanina Svetlana A. - Dr. Sc., Empress Catherine II Saint Petersburg Mining University, Saint-Petersburg, Russia, e-mail: svet_spb@mail.ru, ORCID ID: 0000-0001-7675-865X.

Abstract: *Relevance.* The mining industry is one of the most effective and economically profitable industries. The complication of mining conditions associated with the development of northern territories requires the reliability of the equipment used. The problem of ensuring the performance of the main components of excavators operating in the zone of permafrost soils is not new, but remains relevant to date. *Objective.* The aim of the work is to develop scientifically grounded recommendations allowing mining companies to increase the service life of excavator bucket teeth used in difficult conditions of northern territories. *Methods.* The paper analyses the causes of excavator bucket teeth destruction, based on which it was established that it is the quality of tooth crown casting that determines the further serviceability of the part. *Results and conclusions.* The analysis has shown that dendrite boundaries, which are areas with inhomogeneous chemical composition formed in the process of metal crystallisation, are weak points in the material structure of excavator teeth crowns. The cumulative effect of defects during operation, especially in conditions of perennially frozen soils, where loads on teeth are increased due to the strength of frozen rocks, leads to premature failure of excavator bucket crowns. Improvement of casting quality and application

of properly selected heat treatment will contribute to a significant increase in the serviceability of mining tools.

Keywords: cast alloy steel; wear resistance, casting defects, microstructure, hardness, tooth crown, excavator bucket.

Acknowledgment: *The research was supported by the Russian Science Foundation grant No. 24-29-00713, https://rscf.ru/project/24-29-00713/*

Б.С. Ермаков[1], О.В. Швецов[1], С.Б. Ермаков[1], С.А. Вологжанина[2], 2025.
[1] Ұлы Петр Санкт-Петербург политехникалық университеті, Санкт-Петербург, Ресей;
[2] Императрица Екатерина II Санкт-Петербург тау-кен университеті, Санкт-Петербург, Ресей.
E-mail: svet_spb@mail.ru

КАРЬЕР ЭКСКАВАТОРЫНЫҢ БАСТАУЛАРЫНЫҢ ӨНІМДІЛІГІНЕ ҚОЙЫЛҒАН МИКРО ҚҰРЫЛЫМЫНЫҢ ӘСЕРІН ЗЕРТТЕУ

Ермаков Борис Сергеевич – Техника ғылымдарының докторы, профессор, Ұлы Петр Санкт-Петербург политехникалық университеті, Санкт-Петербург, Ресей, e-mail: ermakov_bs@spbstu.ru, ORCID ID: 0009-0008-0932-2408;
Швецов Олег Викторович – Техника ғылымдарының кандидаты, Ұлы Петр Санкт-Петербург политехникалық университеті, Санкт-Петербург, Ресей, e-mail: shvetsov_ov@spbstu.ru, ORCID ID: 0000-0001-9368-4074;
Ермаков Сергей Борисович - Ұлы Петр Санкт-Петербург политехникалық университеті, Санкт-Петербург, Ресей, e-mail: ermakov_sb@spbstu.ru, ORCID ID: 0000-0003-4243-0984;
Вологжанина Светлана Антониновна Техника ғылымдарының докторы, доцент, Императрица Екатерина II Санкт-Петербург тау-кен университеті, Санкт-Петербург, Ресей, e-mail: svet_spb@mail.ru, ORCID ID: 0000-0001-7675-865X.

Аннотация. *Өзектілігі.* Тау-кен өнеркәсібі ең тиімді және экономикалық жағынан үнемді салалардың бірі. Солтүстік аумақтарды игерумен байланысты тау-кен жұмыстарының күрделенуі пайдаланылатын жабдықтың сенімділігін талап етеді. Мәңгі мұзды топырақ аймағында жұмыс істейтін экскаваторлардың негізгі компоненттерінің жұмысын қамтамасыз ету қордаланған әрі бүгінгі күнге дейін өзекті болып қала береді. *Мақсаты.* Жұмыстың мақсаты тау-кен компанияларына солтүстік аумақтардың қиын жағдайларында қолданылатын экскаватор шелектерінің тістерінің қызмет ету мерзімін ұзартуға мүмкіндік беретін ғылыми негізделген ұсыныстарды әзірлеу. *Әдістері.* Мақалада экскаватор шелегіндегі тістердің бұзылу себептері талданады, соның негізінде бөлшектің одан әрі жұмысқа жарамдылығын анықтайтын тіс тәжін құю сапасы екені анықталды. *Нәтижелер мен қорытындылар.* Талдау көрсеткендей, металл кристалдану процесінде түзілетін біртекті емес химиялық құрамы бар аймақтар болып табылатын дендрит шекаралары

экскаватор тістерінің тәждерінің материалдық құрылымындағы әлсіз нүктелер болып табылады. Жұмыс кезіндегі ақаулардың кумулятивтік әсері, әсіресе мұздатылған жыныстардың беріктігіне байланысты тістерге жүктеме күшейетін көпжылдық мұздатылған топырақтар жағдайында, экскаватор шелектерінің тәждерінің мерзімінен бұрын істен шығуына әкеледі. Құю сапасын жақсарту және дұрыс таңдалған термиялық өңдеуді қолдану тау-кен құралдарының жарамдылығын едәуір арттыруға ықпал етеді.

Түйін сөздер: легирленген болат; тозуға төзімділік, құю ақаулары, микроқұрылым, қаттылық, тіс тәжі, экскаватор шелегі.

Б.С. Ермаков[1], О.В. Швецов[1], С.Б. Ермаков[1], С.А. Вологжанина[2], 2025.
[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия;
[2] Санкт-Петербургский горный университет императрицы Екатерины II Санкт-Петербург, Россия.
E-mail: ermakov_bs@spbstu.ru

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ЛИТОЙ МИКРОСТРУКТУРЫ НА РАБОТОСПОСОБНОСТЬ КОРОНКИ КАРЬЕРНОГО ЭКСКАВАТОРА

Ермаков Борис Сергеевич – доктор технических наук, профессор, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, e-mail: ermakov_bs@spbstu.ru, ORCID ID: 0009-0008-0932-2408;
Швецов Олег Викторович – кандидат технических наук, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, e-mail: shvetsov_ov@spbstu.ru, ORCID ID: 0000-0001-9368-4074;
Ермаков Сергей Борисович – Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, e-mail: ermakov_sb@spbstu.ru, ORCID ID: 0000-0003-4243-0984;
Вологжанина Светлана Антониновна – доктор технических наук, доцент, Санкт-Петербургский горный университет императрицы Екатерины II, Санкт-Петербург, Россия, e-mail: svet_spb@mail.ru, ORCID ID: 0000-0001-7675-865X.

Аннотация. *Актуальность.* К одной из самых эффективных и экономически рентабельных отраслей относится горнодобывающая промышленность. Усложнение условий добычи, связанное, с освоением северных территорий, требует обеспечения надежности применяемого оборудования. Проблема обеспечения работоспособности основных узлов экскаваторов, эксплуатируемых в зоне многолетнемерзлых грунтов не новая, но остаётся актуальной до настоящего времени. Экскавация пород в этих регионах затруднена повышенной прочностью пород за счет ледового смерзания кусков породы после вскрышных работ и требует нового подхода к производству быстросменного инструмента ковшей экскаваторов и погрузчиков. *Цель.* Цель работы состоит в том, чтобы разработать научно обоснованные рекомендации, позволяющие горнодобывающим компаниям увеличить срок службы зубьев ковшей экскаваторов, используемых в сложных условиях северных территорий. *Методы.* В работе проведен анализ причин разрушения зубьев ковшей экскаваторов, на основании которого установлено, что именно качество литья коронок зубьев определяет дальнейшую работоспособность детали. *Результаты и выводы.* Проведенный анализ показал, что границы дендритов, представляющие собой области с неоднородным химическим составом, формирующиеся в процессе кристаллизации металла, являются слабыми местами в структуре материала коронок зубьев экскаватора. Совокупное влияние дефектов в процессе эксплуатации, особенно в условиях многолетнемерзлых грунтов, где нагрузки на зубья повышены из-за прочности смерзшихся пород, приводит к преждевременному выходу из строя коронок ковшей экскаваторов. Таким образом, повышение качества литья, направленное на снижение количества и размеров указанных дефектов, и применение правильно подобранной окончательной термической обработки, которая позволит повысить прочность и вязкость металла, будет способствовать существенному повышению работоспособности горнодобывающего инструмента, снижая риск разрушения и увеличивая срок его службы.

Ключевые слова: литая легированная сталь, износостойкость, дефекты отливки, микроструктура, твердость, коронка зуба, ковш экскаватора

Introduction. Hard rock quarrying is the most efficient method of mineral extraction (Litvinenko, 2022; Kazanin, 2020; Teplyakova, 2022). Hard rock is extracted by excavation with wear-resistant tools (Zubov, 2022). The smooth operation of mining tools is largely determined by the wear resistance of bucket teeth and their crowns (Sudarikov, 2022).

The best known wear-resistant steel with durability under friction, pressure and impact is steel 110G13L (Gadfield steel) (Bolobov, 2022), which has an increase in strength and wear resistance with increasing degree of deformation (Sekhar, 2023; Miladinov, 2023), however, as shown by studies (Bolobov, 2022; Prysyazhnyuk, 2022; Pobegailo, 2021) in the operation of bucket crowns and teeth, cutting tools made of steel 110G13L do not have sufficient serviceability (Yungmeyster, 2022; Klevtsov, 2023; Turdiyev, 2022). Nowadays, carbon and alloy steels and cast irons are used for manufacturing of teeth of excavator buckets and crowns. When excavating highly abrasive rocks after their drilling and blasting, the teeth and crowns of excavator buckets are operated under extreme conditions of abrasive wear (Kondratenko, 2020), which leads to their rapid failure. Therefore, increasing the efficiency of teeth and crowns of mining excavators is an urgent task.

As shown in (Nasonov, 2020), the leading factor determining the serviceability of teeth and crowns is the quality of casting and stability of the microstructure of the cast material. In this regard, there is a problem of improving the quality of cast parts, which is especially important for highly non-equilibrium structures of castings of bucket mining excavators. Cast steel of teeth and crowns of the excavator bucket has an inherently defective microstructure in the form of micropores, sinks and cracks, as well as a high level of chemical heterogeneity - liquation and segregation of basic alloying and impurity elements, large irregular primary grains (Widder, 2023). The authors of many works, including (Kazakov, 2014; Mishnev, S.V.; Galata, 2023), analyzed the causes of tooth and crown fracture and showed that the foci of fracture, in most cases, are casting defects - sinks, failures and macrocracks, contaminated grain boundaries, enriched with impurity elements with low resistance to brittle fracture. The physical nature of such defects is different and is caused by both improperly selected melting, casting and heat treatment modes and unsatisfactory properties of the charge material used. Analysis of studies by a number of authors, including (Maksarov, 2021; Ivanov, 2020), has shown that the quality of the cast microstructure of the material determines its properties, hence, this factor affects tooth wear. At present, most of the works aimed at the development of methods to improve the serviceability of teeth are devoted to the study of the wear process itself, the data on the study of the structure and the influence of material quality on the wear resistance of teeth and crowns of excavator are practically absent. The purpose of this work is to study teeth and crowns of excavator buckets after long-term operation in order to find out the reasons for their accelerated failure.

Methods and materials.

Four post-use crowns were provided for the study: a Cat 391 (ESCO 65SV2AG) excavator crown; a VOLVO 350 crown; a Cat 988 (CAT 467-9815) crown; and an EKG-10M crown. The appearance of the crowns is shown in Figure 1. The chemical composition of the material was determined using the Iskroline-100 emission spectrometer according to GOST 54153-2010. Hardness measurements were carried out on hardness tester TR 5006 №85 according to GOST 9013-59. Metallographic studies of samples were carried out with the help of optical microscope Reichert-Jung at magnification ×500 and microhardness measuring device MICRO-DUROMAT 4000E according to GOST 9450-76, Vickers method with a load of 180 g ($HV_{0,18}$). A 3% solution of nitric acid (HNO3) in alcohol was used to reveal the metal microstructure of the samples. The wear surface and microstructure were studied using a SUPRA 55VP WDS scanning electron microscope with X-ray spectral analysis attachment.

a b

c d

Fig. 1. Initial view of crowns, after long-term operation at ore deposits located in the zone of permafrost soils: a - Cat 991k (ESCO 65SV2AG); b - VOLVO 350; c - Cat 988 (CAT 467-9815); d - EKG-10M

Samples were cut from the original crowns in the working part of the tooth, in the core and in the lower part of the edge. All the crowns examined were not fractured; there are longitudinal risks on the outside from wear during prolonged use.

Discussion of the results.

According to the results of research of chemical composition of samples, it was found that the composition of CAT crowns does not correspond to the steel foundry steel according to GOST 977 between 23HGC2MFL and 30H3S3GML, which are among the cold-resistant and wear-resistant steels (tab. 1).

Table 1. Chemical composition of steel of crown samples

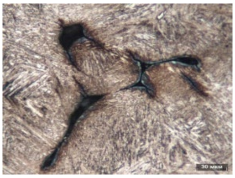
Material	Chemical elements, mass.%							
	C	Si	Mn	Cr	Mo	Ti	S	P
CAT 391k	0,314	>2,2	1,56	0,54	0,33	0,035	0,0028	0,024
CAT 988	0,287	2,17	1,76	0,54	0,21	0,036	0,0027	0,020
Volvo 350	0,295	1,5	1,16	2,07	0,36	0,039	0,0081	0,028
EKG-10M	0,325	0,81	1,07	1,34	0,198	0,026	0,016	0,016

As a result of determination of chemical composition it was found that the Volvo 350 crown is a casting steel of close type 23HGC2MFL. The steel of the EKG-10M crown is a close type of steel 35HGSL. Metallographic analysis of the crown samples showed that there are numerous defects in the metal (Fig. 2).

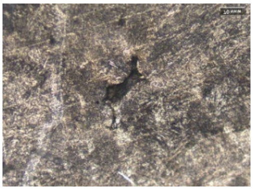
a CAT 391K

b CAT 391K

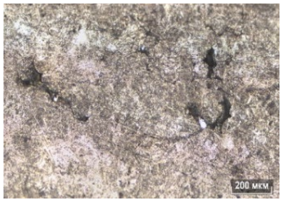
c CAT 988



d CAT 988



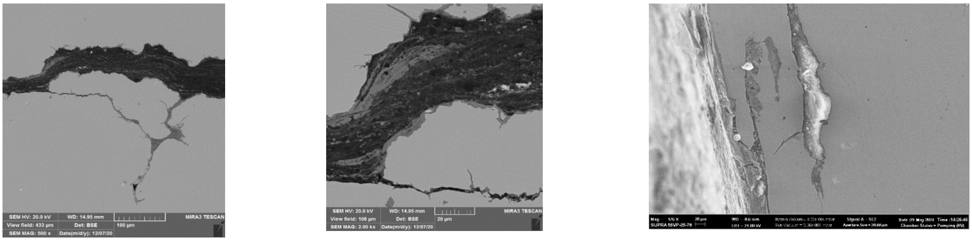
e EKG-10M



f EKG-10M

Fig. 2. Casting defects in dental crowns CAT 391K (a, b); CAT 988 (c, d); ECG-10M (e, f)

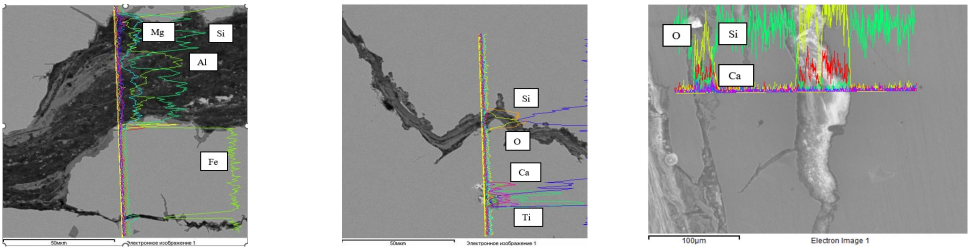
The analysis of microstructures presented in Figures 2 and 3 revealed the presence of characteristic defects significantly affecting the serviceability of the tooth crowns of mining excavators. Figure 2 clearly shows large interdendritic pores, which are a typical defect of foundry origin. These pores, formed in the process of metal crystallisation, are located between the dendritic branches, forming areas of weakened structure. The appearance of these pores is associated with metal shrinkage during solidification, as well as with insufficient supply of liquid melt into the interdendritic intervals, which leads to the formation of voids. The presence of large interdendritic pores creates significant stress concentrators, which under the influence of working loads can initiate the propagation of cracks, contributing to the destruction of the material. The observed pores have a variety of shapes and sizes, which also indicates unstable conditions of melt solidification. The variety of pore shapes may be due to various factors such as uneven temperature distribution, inadequate degassing and sub-optimal sprue system. In addition to the interdendritic pores, Figure 3 shows the different nature of the cracks. A closer look at the structure reveals that some of them were formed as a result of hot cracking that occurred at the crystallisation stage of the metal. Hot cracking, as a rule, occurs at high temperatures, when the metal is in the so-called ‘brittle’ state, in the temperature range between solidus and eutectic transformation temperature, at which the alloy exhibits minimum ductility. Thermal stresses arising during shrinkage and solidification of the metal lead to the formation of intergranular cracks, which, as a rule, have characteristic oxidised and wide-open shores. Oxidation of hot crack edges occurs due to the exposure of freshly formed crack surfaces to atmospheric oxygen at high temperature. This suggests that this type of defect is formed directly during the casting process. In addition to cracks of crystallisation origin, fatigue-type cracks are also present in Figure 3. Their appearance is associated with cyclic loads that occur during the operation of the crown. Fatigue cracks tend to originate at stress concentration points such as corners, grain boundaries and in the area of casting defects. They propagate along grain boundaries and slip planes, contributing to material failure. This type of crack differs from crystallisation cracks in that they have a small opening and are virtually immune to oxidation. This is due to lower temperatures and other conditions of their formation. The presence of fatigue cracks indicates that the material was subjected to cyclic loads, which contribute to the gradual accumulation of damage and the formation of cracks, leading to premature failure of the crown. Thus, the analysis of microstructures presented in Figures 2 and 3 indicates the presence of both foundry defects and operational damage, which together significantly reduce the strength and durability of the tooth crowns of quarry excavators.



a b c

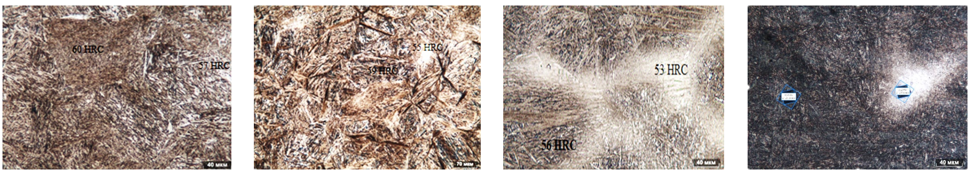
Fig. 3. Electronic images of cracks in the crown metal: a - cold and hot parts of the crack; b - area where the crack develops due to casting defects; c - oxidized areas of the hot crack and operational crack

A detailed analysis of the data presented in Figure 4 and Table 2 allows a deeper understanding of the nature of defects and the heterogeneity of material properties in the tooth crowns of quarry excavators. Figure 4 shows the results of the micro-X-ray spectral analysis carried out in the area of the cracks, which confirms the foundry nature of their origin. This analysis revealed differences in chemical composition between the base metal of the crown and the hot crack area. The base metal, shown in Figure 4, is characterised by the presence of iron, chromium and manganese, typical components of the alloy steel used for crowns. However, a significant enrichment of elements such as aluminium, magnesium, silicon, calcium and titanium is found in the hot crack zone, as can be seen in Figure 4. These elements are characteristic components of non-metallic inclusions that are formed during the process of metal crystallisation from the melt. The appearance of these elements in the crack zone indicates that they have been released as oxide and other non-metallic inclusions during the casting process and tend to concentrate in the interdendritic space regions. Thus, the results of the micro-X-ray spectral analysis in Figure 4 suggest that hot cracks are associated with inhomogeneity of chemical composition and with the formation of non-metallic inclusions during the casting process. The presence of these inclusions favours the occurrence of local stress concentrators, which, in turn, initiate crack initiation. Turning to Table 2, it is worth noting that it contains data on the hardness of the crown material obtained by macro- and microhardness measurements. The results of macro-hardness measurements presented in Table 2 show that the Rockwell hardness (HRC) values for different crown samples are in the range of 45-51 HRC. At the same time, if we consider the microhardness results, it can be observed that the microhardness values measured by the Vickers method have some difference in different parts of the structure, namely between the areas with better and worse etching. Table 2 shows that the microhardness of the regions with the best etching (dendritic regions) is on average higher than the microhardness of the regions with the worst etching (interdendritic regions). This fact indicates the heterogeneity of material properties at the microscale, and confirms that dendritic and interdendritic regions differ in their composition and structure. In particular, the interdendritic regions, which are characterised by the presence of inclusions and liquation formations, have lower hardness compared to the dendritic regions. It should be emphasised, however, that Table 2 does not indicate the specific location on the specimen where the macrohardness measurements were made. In other words, when macrohardness is measured at a single point, the values are averaged over a specific area. Consequently, it is not always correct to rely on macrohardness results to estimate the hardness of the crown material. Analysis of the data in Table 2, combined with the data on microstructure and chemical composition (Figure 4), shows that uneven distribution of microhardness associated with inhomogeneity of structure and chemical composition contributes to accelerated wear and failure of crowns. Thus, the results presented in Figure 4 and Table 2 confirm the presence of both macroscopic and microscopic heterogeneity of crown material properties, which significantly affect their performance characteristics.



a b c

Fig. 4. Electronic images of cracks in tooth metal: a - hot crack area; b - cold crack area; c - combined crack



a) CAT 391K b) CAT 988 c) Volvo 350 d) EKG-10M

Fig. 5. Microstructure of the studied samples CAT 391K (a); CAT 988 (b); Volvo 350 (c); ECG-10M (d) (x200)

Analysis of the microstructure presented in Figure 5 reveals the peculiarities of the structure of the tooth crown metal of quarry excavators. As can be seen from the presented images, the microstructure is non-equilibrium and consists mainly of hardened martensite. Martensite is known to be a product of austenite transformation during rapid cooling, which indicates the heat treatment to which the crowns were subjected. The different degree of etching of the microstructure sections, which can be observed in Figure 5, indicates the inhomogeneity of the composition and stress state of the metal. At the same time on the presented microphotographs clearly observed areas with different etchability, which have a different degree of contrast. These areas can be visually divided into ‘light’ areas with weaker etching and ‘dark’ areas with more intense etching. Further analysis of microstructures showed that the ‘light’ areas correspond to the interdendritic regions of the cast structure, in which a large number of non-metallic inclusions and liquation formations are present. In turn, the ‘dark’ regions correspond to dendritic areas that have a more homogeneous composition and structure. Microhardness measurements performed on the ‘light’ and ‘dark’ areas showed that the microhardness of the ‘light’ areas, with weaker etchability, is generally lower than the microhardness of the ‘dark’ areas, which have a pronounced structure. This indicates that the ‘light-coloured’ areas have lower strength and hardness, and therefore have lower resistance to wear and fracture. In Figure 5, in addition to the non-equilibrium martensitic structure and differences in etchability, the presence of large defects of foundry origin can also be observed. The defects observed in Figure 5 are a confirmation of the results of metallographic studies. Thus, the microphotographs clearly show signs of hot and cold cracks, which have different mechanisms of formation. Hot cracks, as noted earlier, occur during crystallisation, in the brittle temperature range, at which the alloy loses plasticity. As can be seen from the micrographs in Figure 5, these cracks are irregularly shaped and often have a branched structure, which is characteristic of hot cracks arising under the action of thermomechanical stresses. Cold cracks, on the other hand, occur at lower temperatures and are often associated with stress concentrations near defects or grain boundaries. They are more rectilinear in shape and usually have no branching, which is a distinctive feature of this type of crack. Also observed in micrographs is the presence of pores, which are voids in the metal formed due to shrinkage of the metal during solidification. The presence of these pores and cracks in the structure of crowns, confirmed by the data of microstructural analysis presented in Figure 5, indicates that they serve as stress concentrators, which contributes to the rapid propagation of cracks and failure of crowns during operation. Thus, the analysis of microstructures presented in Figure 5 confirms the presence of non-equilibrium martensitic structure, inhomogeneity of etchability, as well as the presence of defects of foundry origin, which together have a negative impact on the performance of crowns of teeth of mining excavators.

Table 2. Hardness values of samples

Образец	Hardness, HRC				Microhardness, $HV_{0,18}$	
	1	2	3	medium	area of poor etching	area with good etching
Cat-391	49	50	50	50	57	60
Cat 988	50	51	49	50	55	59
Volvo -350	45	46	45	45	53	56
EKG-10M	51	49	49	50	52	46

The mechanism of formation of hot cracks is as follows: at casting temperatures below the yield point, a crystalline framework is formed and the alloy becomes brittle. Begins to contract, losing its ability to flow like a liquid and gaining some strength. The resulting stresses reach the tensile strength of the alloy, resulting in the formation of cracks in the casting. Further development of the crack occurs by fatigue mechanism, which leads to accelerated fracture and failure of mining excavator bucket teeth, which is the cause of accelerated failure. It was found that molybdenum, titanium and other refractory elements, which are introduced into steel to improve crack resistance hot cracks, which prevent the growth of grains and the formation of harmful impurities in the base metal, are in large carbide inclusions, not associated with the matrix, and almost completely absent from the solid solution. It was found that the control of the standard method of macrohardness measurement averages the result and does not provide an objective picture of the hardness distribution, so there was a need for additional studies to measure the microhardness of the material. The use of this method provides information on the equilibrium of the structure. The microhardness results showed that there are areas with different microhardness, i.e. different properties predominate in the material. Different hardness is observed in the dendritic and interdendritic space. The hardness is higher in the dendrites and it is lower in the interdendritic space. It is known that wear and hardness are interrelated processes. In the areas with lower hardness (interdendritic spaces) wear occurs faster. Thus, the main reason for accelerated failure of excavator teeth is the superimposition of various microstructural defects associated with imbalance of metal microstructure and imperfection of casting process technology. Consequently, to improve the efficiency, it is not only necessary to improve the casting quality, but it is also necessary to either change the cooling mode to equalize the structure or heat treatment to equalize the structure.

Conclusion.

The conducted research allowed establishing that the serviceability of the tooth crowns of quarry excavators is determined by the peculiarity of the initial cast structure and the presence of defects of casting origin. Metallographic analysis revealed typical casting defects, which are characteristic of large castings. Casting defects, in particular cracks, lead to accelerated destruction and failure of excavator bucket crowns. However, along with typical defects, microstructure heterogeneity was found, differing in chemical composition and hardness. Such heterogeneity is associated with the dendritic structure of the initial cast billet. In the process of analyzing the working surface of the crowns, areas of increased and decreased hardness were found, with the areas of decreased hardness wearing faster.

Harder micro-volumes of metal are chipping away from the working surface of the crowns and softer areas are wearing faster. Thus, the results of the work showed that in order to ensure the serviceability of the bucket crown of mining excavators, it is necessary to improve the quality of casting and optimize the heat treatment of castings to align the structure throughout the castings.

References

Bolobov, V.I., Akhmerov, E.V., Rakitin, I.V. (2022) Influence of rock type on wear patterns of excavator bucket tooth crowns, Mining Informational and analytical Bulletin, 6-2:189-204. DOI: 10. 25018/0236_1493_2022_62_0_189

Galata, L.A., Ermakov, B.S., Kancev, R.G., Karzina, J.S. (2023) The Influence of Microstructure Quality on the Efficiency of Bucket Teeth of Career Excavators, Key Engineering Materials, 941: 107–112. DOI: 10.4028/p-m5od44

Ivanov, S.L., Ivanova, P.V., Kuvshinkin, S.Yu. (2020) Estimation of operating time of quarry excavators of perspective model range in real operating conditions, Journal of Mining Institute, 242: 228–233. DOI: 10.31897/pmi.2020.2.228

Kazakov, A.A., Lyubochko, D.A., Ryaboshuk, S.V., Chigintsev, L.S. (2014) Investigation of the nature of non-metallic inclusions in steel using an automatic particle analyser, Non-ferrous Metals - Ferrous Metals, 4: 85-90.

Kazanin, O.I., & Ilinets, A.A. (2022) Ensuring the excavation workings stability when developing excavation sites of flat-lying coal seams by three workings. Journal of Mining Institute, 253(1): 41-48. DOI: 10.31897/PMI.2022.1

Klevtsov, V.A., Timofeev, D.Y., Khalimonenko, A.D. (2023) Improved Design of Manufacturing Processes for Mining Machines. Basing Concepts, Russian Engineering Research, 43(11): 1367-1375. DOI: 10.3103/S1068798X23110151

Kondratenko, A.S. (2020) Technological aspects of cased wells construction with cyclical-flow transportation of rock, Journal of Mining Institute, 246: 610-616. DOI: 10.31897/PMI.2020.6.2

Litvinenko, V. (2020) Foreword: Sixty-year Russian history of Antarctic sub-glacial lake exploration and Arctic natural resource development, Geochemistry, 80(3): 125652. DOI: 10.1016/j. chemer.2020.125652.

Maksarov, V.V., Khalimonenko, A.D., Olt, J. (2021) Improvement of efficiency of metal recycling in metallurgical production, Chernye Metally, 3: 45-51. DOI: 10.17580/chm.2021.03.08

Miladinov, M., Sedmak, S., Djordjevic, B., Sedmak, A., Vucetic, F., Milivojevic, A. (2023) Repairing of cracks on tooth gear ring of a bucket-wheel excavator, Procedia Structural Integrity 48: 27-32. DOI: 10.1016/j.prostr.2023.07.106

Mishnev, S.V., Berezyuk, V.G., Kuzembayev, S.B., Sikhimbayev, M.R., Absadykov, B.N., Dementeva, I.S. (2020) Influence of the geometric shape of the mold on the cast billet structure for forming processes, News of The National Academy of Sciences of The Republic of Kazakhstan. Series of Geology and Technical Sciences, 1: 114 – 121 DOI: 10.32014/2020.2518-170X.14

Nasonov, M.Y., Lykov, Yu, V.V., Chong, D.D. (2020) Research of service life and durability of metal structures of excavators after expiry of service life, Ugol, 2: 13-17. DOI: 10.18796/0041-5790-2020-2-13-17

Pobegailo, P.A., Kritskiy, D.Yu., Gilmashina, T.R. (2021) Wear of elements of quarry excavators: analysis of the current state of the problem, Mining Informational and analytical Bulletin 2: 64-74. DOI: 10.25018/0236-1493-2021-2-0-64-74

Prysyazhnyuk, P., Ivanov, O., Matvienkiv, O., Marynenko, S., Korol, O., Koval, I. (2022) Impact and abrasion wear resistance of the hardfacings based on high-manganese steel reinforced with multicomponent carbides of Ti-Nb-Mo-V-C system, Procedia Structural Integrity, 36: 130-136. Doi: 10.1016/j.prostr.2022.01.014.

Sekhar, B., Long, F., Sikandar, A., Shimin, L. (2023) Advances in coal mining technology and sustainable mining techniques, Woodhead Publishing Series in Energy, 1: 263-321. DOI: 10.1016/ B978-0-12-824328-2.00011-X

Sudarikov, S.M., Yungmeister, D.A., Korolev, R.I., Petrov, V.A. (2022) On the possibility of reducing man-made burden on benthic biotic communities when mining solid minerals using technical means of various designs, Journal of Mining Institute 253: 82–96. DOI: 10.31897/PMI.2022.14

Teplyakova, A.V., Zhukov, I.A., Martyushev, N.V. (2022) Application of drilling machines with impact cam mechanism in various mining and geological conditions, Sustainable Development of Mountain Territories, 14(3): 501-511. DOI: 10.21177/1998-4502-2022-14-3-501-511

Turdiyev, S., Djuraev, R. (2022) Experimental results on the effectiveness of an improved excavator bucket tooth design, The American Journal of Engineering and Technology, 4(03): 1-13. DOI: 10.37547/tajet/Volume04Issue03-01

Widder, L., Rojacz, H., Adam, K., Kuttner, A., Varga, M. (2023) Abrasive wear protection in material handling: Mechanism-based combination of lab-experiments for optimal material selection, Wear, 530–531: 204979. DOI: 10.1016/j.wear.2023.204979

Yungmeyster, D.A., Isaev, A.I., Gasymov, E.E. (2022) Substantiation of dth air drill hammer parameters for penetration rate adjustment using air flow, Gornyi Zhurnal, 7: 72-77. DOI: 10.17580/gzh.2022.07.12

Zubov, V.P., Phuc, L.Q. (2022) Development of resource-saving technology for excavation of flat-lying coal seams with tight roof rocks (on the example of the quang ninh coal basin mines), Journal of Mining Institute, 257: 795-806. DOI: 10.31897/PMI.2022.72

CONTENTS

Zh.M. Aitulova, B.O. Yessimov, T.A. Adyrbaeva, E.S. Dubinina, M.E. Kurbanbayev
SYNTHESIS OF IMPORT-SUBSTITUTING BLUE ULTRAMARINE BASED ON MINERAL RAW MATERIALS FROM UNIQUE DOMESTIC DEPOSITS..6

M.R. Aktayev, L. Akbayeva, Y. Pangaliyev, N.A. Baubek
RESEARCH OF THE CHARACTERISTICS OF UNDERGROUND AND SURFACE POLLUTION OF LAKE KISHKENSOR ON THE TERRITORY OF THE SEMIPALATINSK TEST SITE..19

G.Zh. Bulekbayeva, O.G. Кikvidze, A.U. Tabylov, A.Z. Bukayeva, N.B. Suyeuova
DEVELOPMENT OF A METHOD FOR CALCULATING THE ONE-DIMENSIONAL PROBLEM OF PLASTIC DEFORMATION OF THE DEPOSITED LAYER DURING THE RESTORATION OF FLAT SURFACES OF PARTS..34

Y.G. Gilazhov, M.Z. Muldakhmetov, A.Sh. Kanbetov, D.K. Kulbatyrov, E.B. Zhunussova
STRENGTHENING OF SOILS BASED ON OILED SOIL................................47

B.S. Ermakov, O.V. Shvetsov, S.B. Ermakov, S.A. Vologzhanina
INVESTIGATION OF THE INFLUENCE OF CAST MICROSTRUCTURE ON THE OPERABILITY OF THE CROWN OF A QUARRY EXCAVATOR...........59

Y.Kh. Kakimzhanov, K.T. Kyrgyzbay, S.M. Zhumatayev, T.A. Bazarbayeva, G.T. Kunypiyaeva
ASSESSMENT OF SOIL CONTAMINATION OF THE WEST KAZAKHSTAN REGION WITH HEAVY METALS AS A RESULT OF INDUSTRIAL ACTIVITY..72

K.Ye. Kaliyeva, Ye.D. Zhaparkulova, A.R. Vagapova, M.S. Nabiollina, L.M. Ryskulbekova
THE INFLUENCE OF CLIMATIC AND ANTHROPOGENIC FACTORS ON THE HYDROLOGICAL REGIME OF THE BASINS OF THE SHU-TALAS RIVERS..91

O.A. Kolenchukov, V.A. Fayfer, V.V. Bukhtoyarov
PREDICTION OF THE REMAINING SERVICE LIFE OF PUMPING UNIT ELEMENTS BASED ON REGULARIZATION OF RECURRENT NEURAL NETWORKS.....107

A.M. Mikayilov, F.M. Jafarova, A.Z. Hajiyeva
THE GROUPING OF MILL LANDSCAPES BY DESERTIFICATION FACTORS AND RISKS.....128

L.M. Mustafa, I.K. Ablakatov, B.M. Baiserikov, M.B. Ismailov, V.R. Zhumakanova
RESEARCH ON ARMOR STEEL TECHNOLOGY AND WAYS TO IMPROVE ITS MECHANICAL PROPERTIES.....140

M. Nurpeisova, O. Kurmanbaev, Zh. Turegaliyeva, Zh. Nukarbekova, O.Baiturbay
INNOVATIVE TECHNOLOGIES IN THE URBAN PLANNING CADASTRE.....155

Ya.N. Parshakova, A.O. Ivantsov
DEVELOPMENT OF A METHOD OF WATER TREATMENT IN THE PROCESS OF PREPARATION FOR UTILISATION OF PRODUCTION WASTE.....169

B.T. Ratov, V.L. Khomenko, Z.G. Utepov, Ye.A. Koroviaka, A.A. Seidaliyev
BLADE BIT DRILLING IN KAZAKHSTAN: ACHIEVED RESULTS, UNRESOLVED ISSUES.....182

G.K. Umirova, E.M. Toleubekov, S.K. Muratova, A.K. Isagalieva, Z.N. Ablesenova
THE EFFICIENCY OF A COMPLEX OF GEOPHYSICAL METHODS BY EXAMPLE OF THE ATASU ORE DISTRICT.....202

O.G. Khayitov, L.S. Saidova, A.A. Umirzokov, M.A. Mutalova, N.M. Askarova
RATIONAL TECHNOLOGICAL SCHEME FOR TRANSPORTING ROCK MASS FROM DEEP QUARRY.....218

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:

www:nauka-nanrk.kz

http://www.geolog-technical.kz/index.php/en/

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*

Редакторы: *Д.С. Аленов, Ж.Ш.Әден*

Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.02.2025.

Формат 70x90 1/16. Бумага офсетная. Печать – ризограф.

14,5 п.л. Тираж 300. Заказ 1.

РОО «Национальная академия наук РК»

050010, Алматы, ул. Шевченко, 28, т. 272-13-19